Coupled Ocean-Atmosphere Modeling of the Coastal Zone

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LONG-TERM GOAL

The long-range goal of this project is to improve our ability to understand and predict environmental conditions in the coastal zone.

OBJECTIVES

The primary scientific objectives of the proposed research are to use a coupled atmosphere--ocean model to investigate and quantify the interaction between the oceanic and atmospheric boundary layers and its effect on environmental conditions in the coastal zone. The main focus will be on boundary layer interactions under coastal upwelling conditions, in which cold, upwelled ocean surface water induces the development of stable internal boundary layers in the atmosphere and thereby reduces low-level winds and surface stress. Research will also investigate the effects of coastal terrain and diurnal heating and the interaction of forced coastal atmospheric flows on the ocean circulation.

APPROACH

The approach used in this project is to combine numerical model results with in-situ and remote-sensing observations to understand and quantify physical processes in the coastal, coupled atmosphere-ocean and test their representation in mesoscale atmospheric models.

WORK COMPLETED

Efforts this year have focused on understanding the relative importance of atmosphere-ocean coupling in comparson with coastal terrain and diurnal forcing. Simulations were conducted using an idealized

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coastline with a single point, and emphasized how coastal features interact with diurnal heating and boundary layer coupling. Results with and without coupling are being analyzed to determine how both the atmosphere and ocean respond, and will be reported in a publication in preparation.

RESULTS

Atmospheric Circulation

Simulations with the coupled Naval Research Laboratory (NRL) COAMPS and Regional Ocean Modeling System (ROMS) were conducted for an idealized coastal terrain consisting of a single cape with a periodic north-south boundary. Forcing conditions representing typical northerly winds during the summer months were applied over a 14-day period with diurnal heating. Wind stress plots averaged over the last 7 days at four different times are shown in Figure 1 and demonstrate the influence of the daily heating cycle on the simulated wind fields. Two features stand out in this figure; the formation of a distinct expansion fan in the late afternoon and the almost flat wind field in the early morning hours. Also noticeable in this simulation is the relativel weak near-coastal winds that result from decoupling over the upwelling zone within ~50 km of the shoreline.

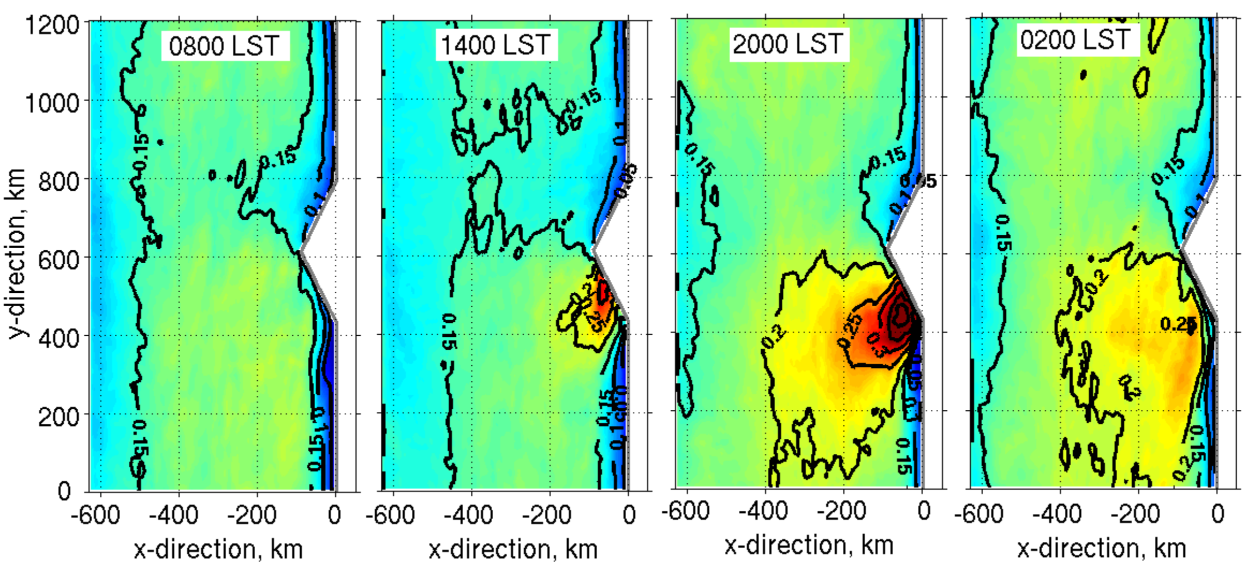


Figure 1. Wind stress magnitude, averaged over the last 7 days of the forecast at the following hours: (a) 0800 LST ("morning"), (b) 1400 LST ("daytime"), (c) 2000 LST ("evening"), (d) 0200 LST ("night").

Figure 1 suggests that coupling from upwelling is overwhelmed by the effects of coastal terrain and diurnal forcing in the lee of coastal points. For example, we note that the maximum winds in the afternoon are very near the the coastline on the southern edge of the point. When diurnal forcing is weak in the early morning, the wind stress tends to correlate well with colder sea-surface temperatures (SST).

A more quantitative method for diagnosing the effects of coupling can be produced by examing the relationship between the wind stress curl and divergence with downwind and crosswind wind direction

(Maloney and Chelton 2006). A scatterplot between the corresponding average derivatives of SST and wind stress in the near shore is shown in Figure 2, following Chelton et al. (2007). Values shown are limited to the region within 100 km of the coastline where SST gradients are significant, excluding two coastal ocean gridpoints. The large scatter arises because of the dominant effects of orography on the wind stress curl and divergence fields, which disrupts the correlations between stress and SST that would otherwise develop. Scatter is also produced by the diurnal forcing, which generates large wind stress variations that are not tied to the SST value. Additional analysis shows that the anticipated stress-SST correlation can be found if the orographic effect is removed by differencing the coupled solution with an uncoupled solution obtained with fixed SST, both of which contain similar orographic intensifications. *[Should we show the better results for the difference fields?]*

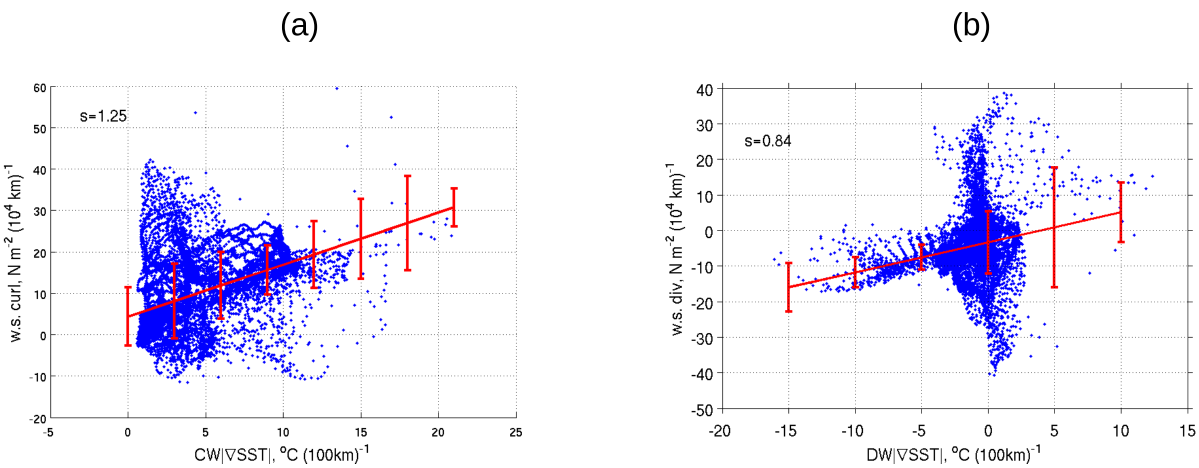


Figure 2. A scatterplot and linear fit between the average wind stress derivatives and SST derivatives shown in Figs.12-13, within the offshore 100km, as follows: a) cross-wind SST gradient vs. wind stress curl, b) wind stress divergence vs. downwind SST gradient.

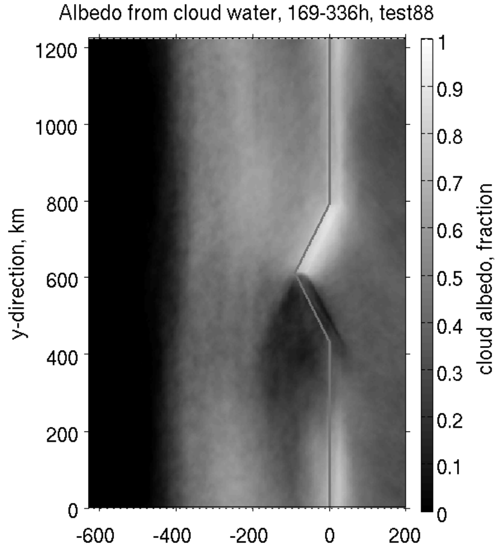
Results from the model also show a strong relationship between the cloudiness and the location of the expansion fan in the lee of the cape. This is demonstrated in Figure 3 showing simulated cloud albedo averaged over the last seven days of the simulation. Notable features in this figure include the relative reduction of cloud cover south of the cape and thicker clouds north of the cape that penetrate inland. Also shown in Figure 3 is a visible satellite image of the western United States, which has similar cloud features at Cape Blanco and Mendicino.

Cloud Formation

Stratus clouds are often observed during periods of upwelling as the marine boundary layer is cooled through upwelling. In our simulations, clouds form along the coast in response to the gradual cooling as shown in figure 3. Two regions, one upwind of the cape an the other downwind of the cape, show a characteristic pattern with increased clouds on the upwind side and decreased clouds over the expansion fan. This pattern is produced by the changing marine boundary layer depth, which is elevated upstream from the point and depressed by the flow around the topography south of the cape.

Observations show a similar behavior when the boundary layer is sufficiently shallow along the west coast of North America.

(a)



(b)

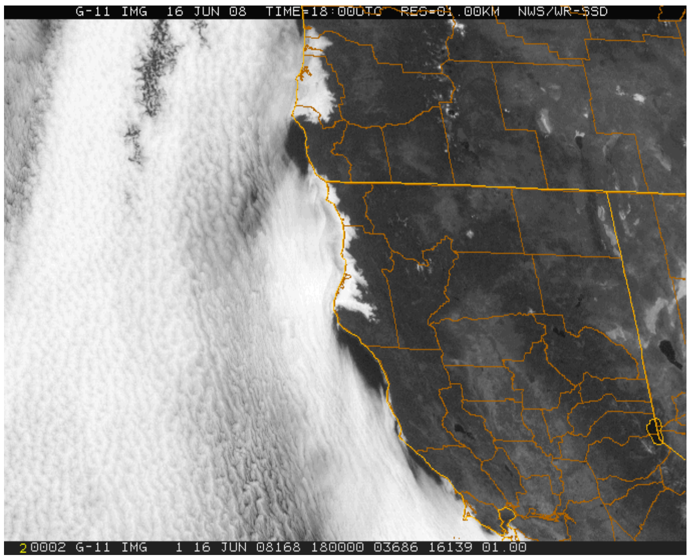


Figure 3. (a) Average cloud albedo calculated from the integrated cloud water, along with (b) a visible satellite image showing the effects of Cape Blanco and Cape Mendocino on coastal stratus.

Ocean Circulation

Ocean simulations with and without coupling were also analyzed to assess the importance of wind stress variations on ocean currents. In the uncoupled case, winds were held constant at the original geostrophic value [*Is this true?? I hope not. It should instead be that the SST is held constant in the atmospheric model from which the wind forcing is taken!*]. Results from these two simulations are shown in Figure 4 and demonstrate how the decreased wind stress along the upwelling zone inhibits the cooling effect of upwelling by reducing the total upwelled water volume. Ocean currents in the coupled case are reduced because of the reduced upwelling, which, by the thermal wind relation, results in a weaker alongshore geostrophic jet.

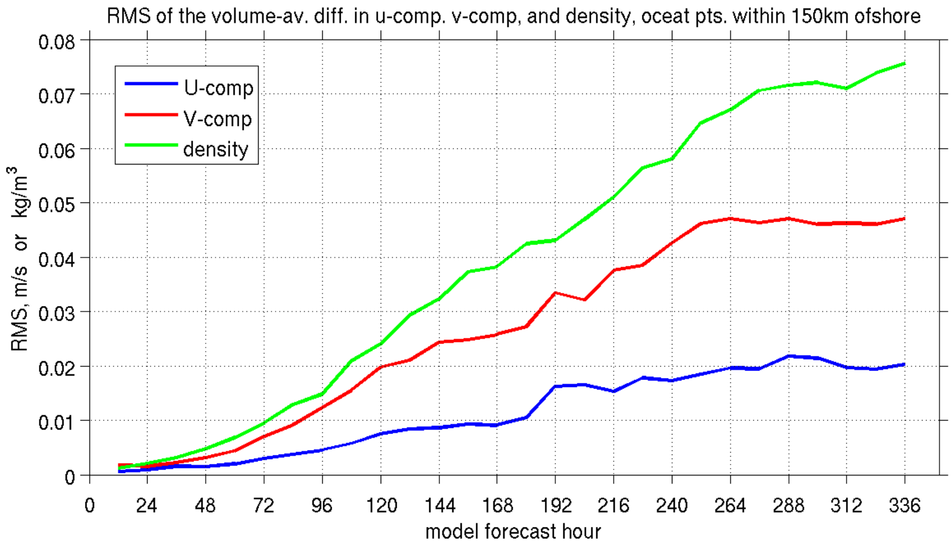


Figure 4. Average differences between the coupled and uncoupled simulations for ocean density and velocity components. Currents are larger in uncoupled case because the wind stress is greater without coupling.

RELATED PROJECTS

Coupling techniques developed as part of this research are currently being used as part of the NOPP Community Sediment Transport Model development.

PUBLICATIONS

Skyllingstad, E.D., and J. B. Edson, 2009: Large-eddy simulation of moist convection during a cold air outbreak over the Gulf Stream. *J. Atmos. Sci*., 66, 1274-1293.